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PRELIMINARY DEVELOPMENT OF ULTRASONIC C-SCAN TEST METHODS AND STANDARDS TO DETERMINE PROJECTILE-ROTATING BAND INTEGRITY

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MATERIALS APPLICATION DIVISION

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ABSTRACT

In the attachment of a copper rotating band to a projectile body, craters, unbonds, and crack systems may develop. These defects may produce serious structural failures or aerodynamic instability.

The ultrasonic C-scan evaluation of rotating bands on 8-inch-diameter projectiles was conducted using both longitudinal and shear angle techniques to assess the integrity of the weld overlay band and the shell body. The longitudinal wave method was used to inspect for unbond areas at the interface of the shell body and rotating band. From this work it was ascertained that ultrasonic C-scanning yields an accurate representation of unbond areas developed during the weld overlay method of attaching rotating bands.

Cracks and craters at the outer diameter of the steel body were investigated by means of the shear angle beam method. It was found that at an optimum shear angle of 45°, longitudinal saw cuts of various depths and also actual weld craters in the steel shell are readily detected and recorded with C-scan techniques.

INTRODUCTION

Fifty XM-650 rocket-assisted projectile (RAP) motor bodies were received from Picatinny Arsenal. The weld overlay rotating band components were to be modified and the bodies used in the manufacture of experimental projectiles. These rounds are preliminary launch vehicle models which will be used in test firings to determine the structural integrity and flight performance characteristics of various experimental components. The successful components will then be incorporated into a final 8-inch-diameter nuclear artillery shell now under development.

The attachment of copper rotating bands to any projectile body usually involves the concentration of a large amount of heat over a relatively small portion of the shell body. This procedure can cause craters and local thermal crack systems to develop in the band or adjacent shell structure. The crack systems can cause serious stress concentrations during launch and result in complete projectile failure in the gun tube or, through abetting band malfunction, cause insufficient spin to be imparted to the round with a resulting loss of aerodynamic stability. In addition, the failure to form a suitable metallurgical bond between the rotating band and the projectile body as evidenced by craters and unbonds can cause spin reduction and bond disengagement with the same adverse effect on flight performance. Prior experience has shown the ultrasonic pulse-echo method to be ideal for investigating the unique defects which can be developed during rotating band attachment. C-scan testing, which produces a cross-sectional view of defects and specimen boundaries normal to the scanning ultrasonic beam, can be readily applied to cylindrical artillery shells for depicting size and shape of unbonds and discontinuities. Because of this, AMMRC was requested to initiate an ultrasonic C-scan investigation of all rounds associated with the nuclear artillery shell program to determine the presence and severity of cracks, craters, and unbonds. This report describes the methods and procedures applied for inspecting these components, the standards used, and limited destructive correlation results.

EQUIPMENT

The following equipment was used in the performance of the tests reported herein:

Transducer (S)
Model: Automation Industries SIL
Serial No: 16303
Style: 57A 8393
Frequency: 5 MHz

Transducer (L)
Model: Panametrics A313
Serial No: 4882
Style: Flat
Frequency: 15 MHz

Pulser-Receiver (S)
Model: Automation Industries 10 N
Serial No: 18033 Type UM

Style: 50E533
Frequency: 5 MHz

Pulser-Receiver (L)
Model: Automation Industries 50A

Transigate H
Model: Automation Industries 50 E
Serial No: 1874-3
Style: 50E664

Recording Amplifier
Model: Automation Industries 50E
Serial No: 50E642
Type: S

C Scanner
Model: Automation Industries 450

UM771 Reflectoscope

(S) and (L) indicate equipment used in shear angle and longitudinal wave tests.

TEST PROCEDURE

Pulse-echo immersion C-scan methods were employed using both longitudinal and shear angle beam measurement techniques to assess the integrity of the shell body and rotating band region of the RAP motor bodies.

Craters and unbonds at the interface of the shell body and rotating band were determined by the longitudinal wave method, while cracks at the outer diameter of the shell body were investigated by means of the shear angle beam method.

Longitudinal Wave Method

The acoustic energy is generated by a transducer situated along a radius in the interior of the cylindrical motor body and at the same vertical height as the top of the rotating band. The transducer and shell body are both positioned in a water-filled tank. The shell body is mounted within the tank on a turntable which rotates at a constant speed. Outside the tank is a 10-inch-diameter cylindrical drum to which a dry electrosensitive paper is attached. The cylindrical drum is in synchronous rotation with the shell body. A stylus whose spark intensity discharge is controlled by the voltage output from the transducer is maintained in continuous contact with the electrosensitive paper. Thus, depending on the voltage output from the transducer, the stylus can be made to mark or leave blank the electrosensitive paper. As the drum rotates, the stylus automatically indexes a preset distance (variable from 0.001" to 0.099" in 0.001" increments) at the rate of 0.015 inch/revolution. In this fashion, a permanent record of the acoustic signature of the motor body is obtained where the vertical and angular coordinates of the record are identical with those of the motor body. The test apparatus is shown in Figure 1.

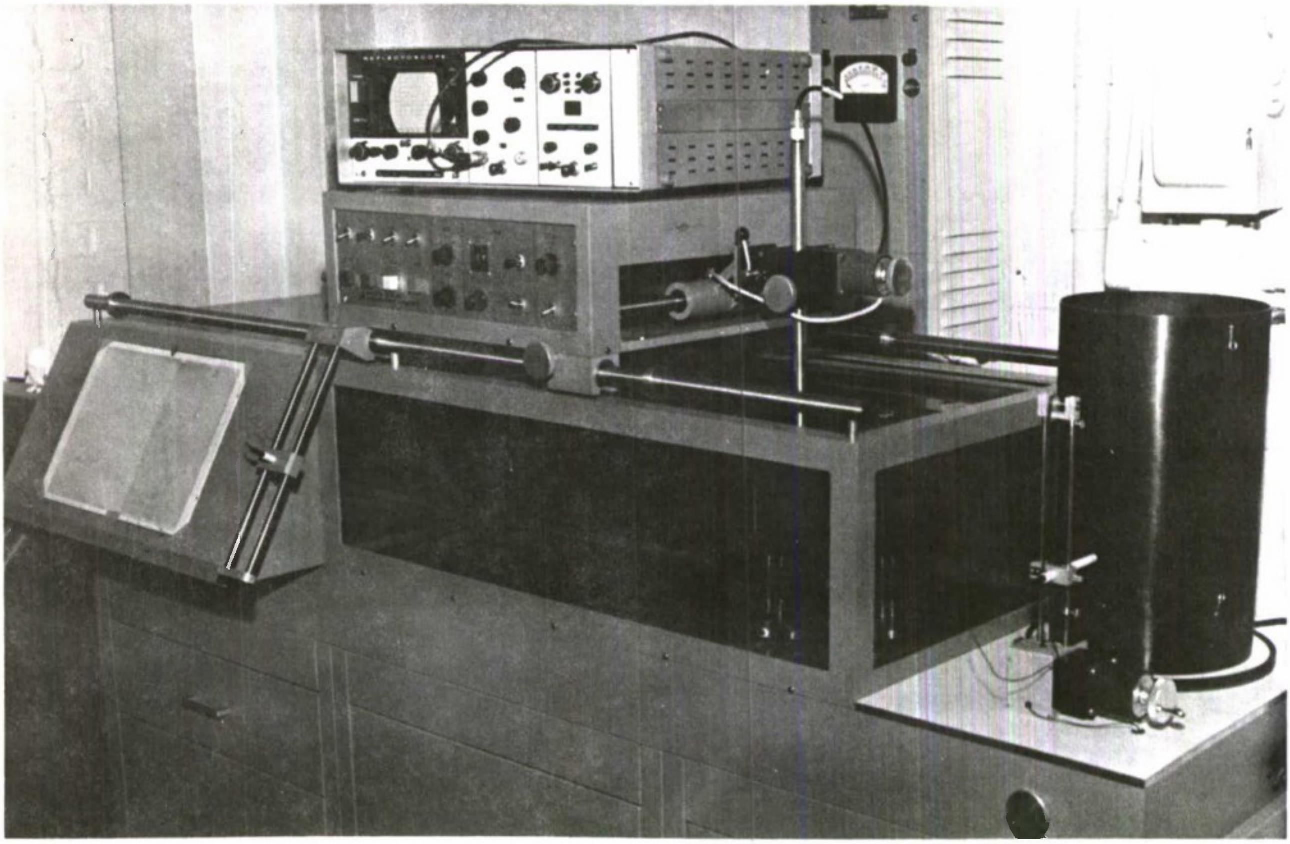

Figure 1. Ultrasonic C-scan inspection test apparatus
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The acoustic energy generated by the transducer is reflected sequentially at the inside diameter of the shell, the interface between the outer diameter of the shell and the inside diameter of the rotating band, and the outer diameter of the band. The reflected signal from the interface of the steel shell and copper band is separated for recording purposes by means of a time gate. Previous tests with similar specimens have established the approximate amplitude of the reflected energy for a satisfactory bond. An increase in the reflected signal amplitude from this value indicates an area that is not completely bonded. Negative black and white C-scan recordings were made of the motor bodies. With this method of recording, the reflected signal has to exceed a preset threshold level to interrupt marking of the recording paper. The threshold level was set so that white areas on the C-scan record indicate completely unbonded areas while black areas indicate those regions where the bond is considered satisfactory.

For this portion of the test it was necessary to employ high-resolution broad band ultrasonic inspection equipment to resolve the interface between the steel shell and the relatively thin finish machined copper band which is 0.017-inch thick in the groove and 0.135-inch thick at the OD.

Shear Wave Method

For the shear wave test, the longitudinal wave transducer is positioned within the interior of the shell body such that the ray path is offset a fixed distance from the parallel shell body radius in order to produce the desired inspection angle and mode of vibration. The offset distance is calculated in accordance with the ray path analysis given in Appendix A. The offset was selected to produce a shear wave with a 45° inspection angle to maximize the reflected energy from a radial crack. In this arrangement the acoustic energy reflected is proportional to the area of the crack plane, therefore an examination of the C-scan record will indicate the approximate dimensions of the crack.

TEST STANDARDS

Unbonds

Previous longitudinal wave C-scan tests on brazed copper rotating bands followed by removal of the copper band have demonstrated that the C-scan record accurately depicts the size and distribution of unbonds. Although only limited data have been compiled for welded overlay rotating bands, it is felt that the process of band attachment is sufficiently similar so that the C-scan records for the weld overlay will yield an accurate representation of the unbonds.

Cracks

In order that equipment sensitivity for detecting cracks could be determined, crack standards were prepared and tested in the following fashion.

A copper rotating band was removed from the RAP motor body using an Enthone "S" stripper thus exposing the projectile band seat. On the band seat surface three longitudinal cuts parallel to the axis of symmetry of the body were made using a slitting saw. The cuts, all approximately 0.12 inch wide and 1.0 inch long were separated on the body by a constant angular arc of 30 degrees. The depths of the three cuts were 0.020 inch, 0.040 inch, and 0.060 inch.

During C-scan testing, adjustments were made to the receiver sensitivity by scanning the standard using the shear wave method so that (1) all cuts appeared; (2) the 0.020-inch cut was suppressed while the 0.040-inch and 0.060-inch cuts appeared; and (3) the 0.020-inch and 0.040-inch cuts were suppressed with only the 0.060-inch cut appearing. All the RAP motor bodies were then C-scanned using the selected sensitivities.

RESULTS AND DISCUSSION

Unbonds

The C-scan record from the standard test specimen developed for brazed bonding procedures is depicted in Figure 2. Grafoil* disks of 1/16, 1/8, and 1/4 inch in diameter, all 0.005 inch thick, were inserted between the steel body and brazing

*Grafoil - Graphite tape manufactured by Union Carbide Corporation

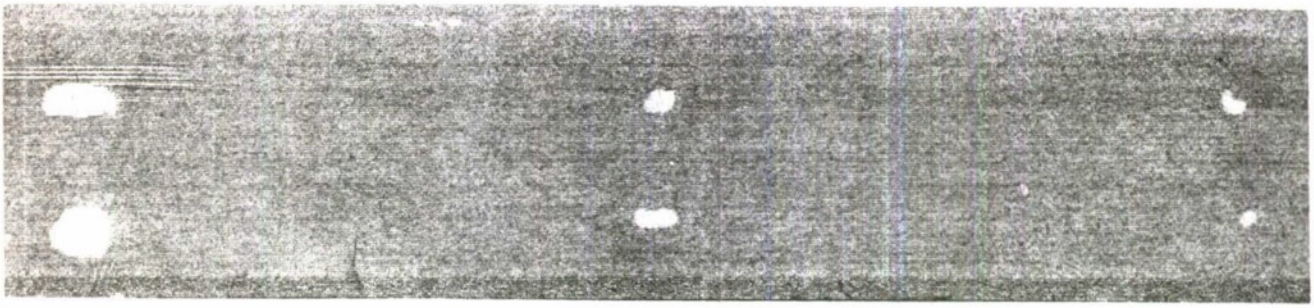

Figure 2. Unbond standards developed for C-scan inspection tests using Grafoil disks

material before the brazing operation. The Grafoil prevented wetting of the mating surfaces during the brazing cycle and thus guaranteed the presence of unbonds of known dimensions. As seen from Figure 2, the unbonds are readily detected through C-scanning, and by adjustment of transducer size and water path, a one-to-one correspondence between the artificial unbond size and C-scan presentation was attainable. As anticipated, subsequent X-ray tests failed to reveal the presence of these unbonded areas. This standard developed for the brazed method of assembly was used to interpret the C-scan results for the weld overlay RAP motor bodies.

Figure 3 illustrates in a very dramatic fashion the success with which the C-scan method details unbonded areas. The actual unbonded areas of the shell were revealed by carefully removing the copper rotating band by machining material along

Figure 3. Unbonded area on XM-650 RAP motor body and corresponding C-scan record
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a circumference in radial increments of 0.001 inch. The associated C-scan is also depicted at the bottom of Figure 3. Similarly, the unbonded areas of the motor body caused by a large crater and the associated C-scan record are presented in Figure 4. The apparent elongation of the unbonds as shown in the records is due to the difference in the recording drum diameter as compared to the shell diameter (10 versus 8 inches). If this deviation is allowed for, then a one-to-one correspondence between the C-scan records and the actual unbonds are established.

The section of a C-scan record shown in Figure 5 indicates the absence of unbonding.

Machined Slots and Craters

A C-scan record of the standard slots machined into the band seat of a RAP motor body is shown in Figure 6. The 0.02-inch-deep slot is at the left of the figure, the 0.04-inch-deep slot at the middle, while the 0.06-inch-deep slot is at the right. All slots are approximately 0.12 inch wide and 1.0 inch long. Figure 7 shows a section of a C-scan record of a weld overlay motor body containing a large crater in the base metal.

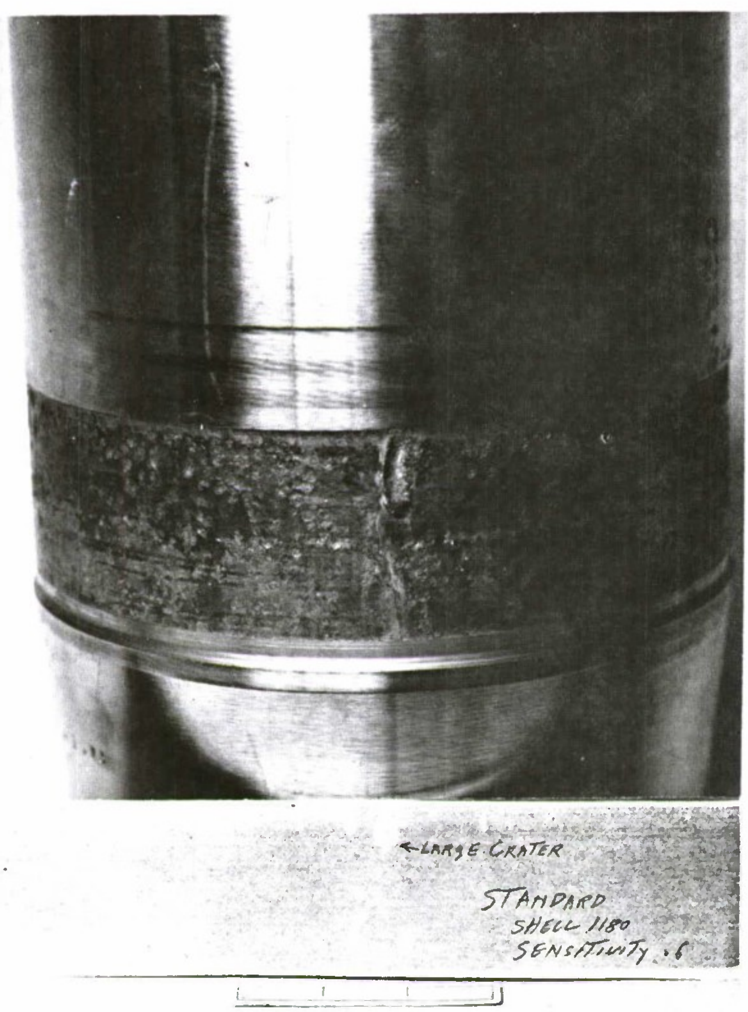

Figure 4. Crater areas on XM-650 RAP motor body and corresponding C-scan record

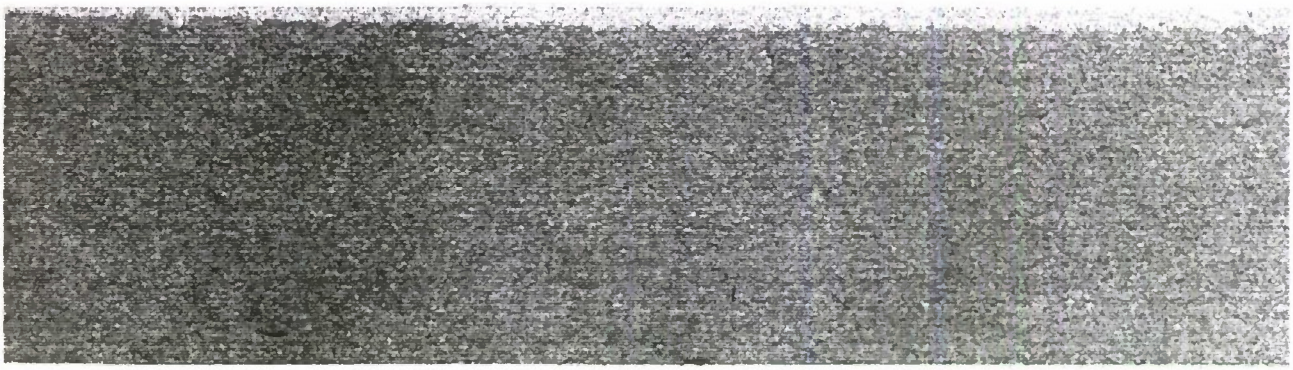

Figure 5. Typical C-scan record of good bond area

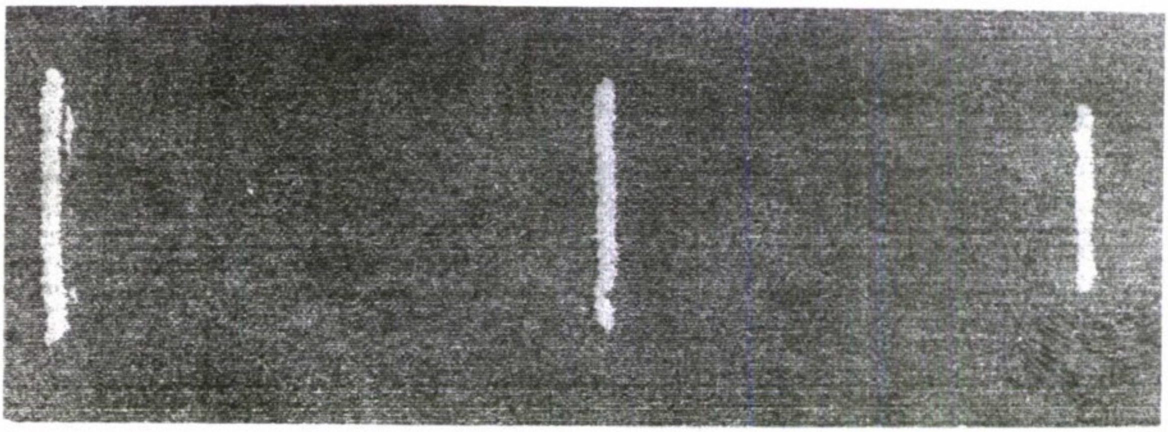

Figure 6. C-scan record of standard machine cuts

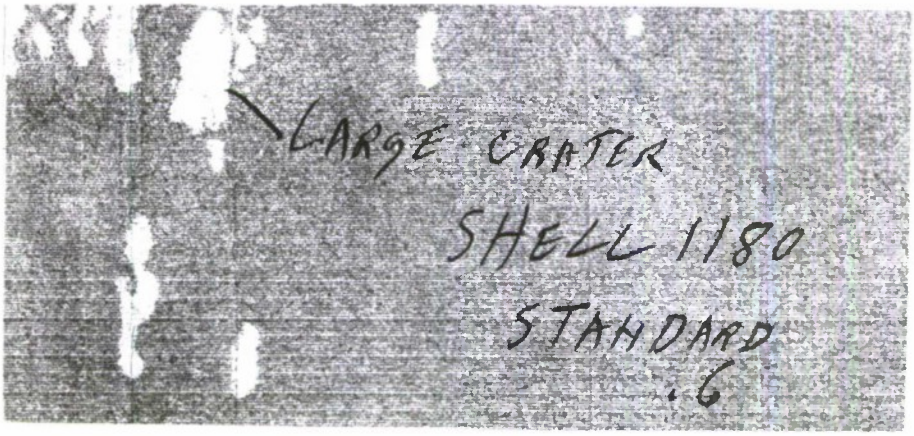

Figure 7. C-scan record of unbond craters

REMARKS

The successful rotating band must transmit the spin engendered by the rifling in the gun tube to the projectile proper and, in addition, must not lift up or disengage in whole or in part from the projectile when the round emerges from the gun. If the rotating band lifts off or partly disengages from the band seat, then an increase in the projected area of the round results with a consequent increase in the drag force. This, in turn, will substantially alter the projectile-range characteristics and minimize, if not eliminate, the probability of impacting the target. Also band disengagement presents a serious safety hazard to friendly personnel.

Spin transmission within the gun tube is dependent on the shear stress capacity of the bond, while both lift-off and disengagement of the band from the projectile depend on the tensile stress of the bond. Because of this, it is essential that the minimum acceptable shear and tensile stresses of the bond required for acceptable flight performance be determined. With this established, the degradation in shear and tensile stresses must be determined as a function of the size, number, and distribution of unbonded areas. This can be accomplished by first calculating the minumum acceptable stresses, then introducing predetermined unbonds of different sizes and distributions and measuring the decrease in stress capacity. These results must then be correlated with the flight performance. In this fashion acceptable and unacceptable unbond patterns may be determined and appropriate standards for acceptance developed for use in C-scan testing.

APPENDIX A. ULTRASONIC RAY PATH ANALYSIS

GENERAL

The ultrasonic device is positioned in water at a location P oriented at some angle γ from the radius OB drawn to the point B at which the energy is incident upon the interior of the cylindrical specimen (cf. Figure A-1).

The incident ray refracts through an angle β in accordance with Snell's law, then impinges on the outer surface of the cylinder where it is reflected back through the specimen. When it reaches the interior of the specimen again it is refracted back into the water.

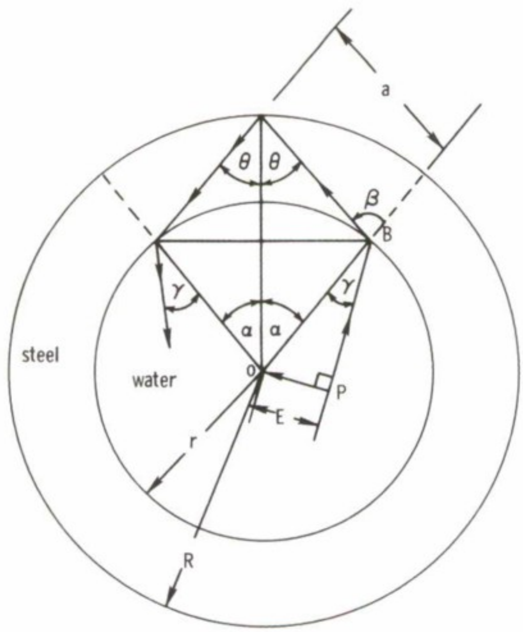

Figure A-1. Ray path during ultrasonic testing of cylinder

OBJECTIVE

To determine as a function of γ, R, and r, the distance 2a which the ray travels through the specimen.

ANALYSIS

From Figure A-1 it is seen that

$$R^2 = a^2 + r^2 + 2ar\cos\beta \tag{A-1}$$

where R = outer radius of cylinder

a = 1/2 the path length of the ray through the specimen

r = inner radius of cylinder

β = angle of ray refraction

Now (A-1) is manipulated to determine a. Thus

$$a^2 + 2ar\cos\beta = R^2 - r^2$$

$$(a + r\cos\beta)^2 = R^2 - r^2 + r^2\cos^2\beta$$

$$a = [R^2 - r^2\sin^2\beta]^{\frac{1}{2}} - r\cos\beta$$

and

$$2a = [D^2 - d^2\sin^2\beta]^{\frac{1}{2}} - d\cos\beta \qquad \text{(A-2)}$$

where D = outer diameter

d = inner diameter

Now the angle β is related to the incident angle γ according to Snell's law or

$$\sin\gamma/\sin\beta = V_w/V_s \qquad \text{(A-3)}$$

where γ = angle of orientation of ray in water

β = angle of orientation of ray in steel

V_w = velocity of sound energy in water (58,500 in./sec)

V_s = velocity of sound energy in steel (126,000 in./sec)

The angles α and Θ are readily determined from the geometry of Figure A-1.

$$(D/2)/\sin(180°-\beta) = (d/2)/\sin\Theta$$

$$\sin\Theta = (d/D)\sin\beta \qquad \text{(A-4)}$$

also

$$a/\sin\alpha = R/\sin\beta$$

$$\sin\alpha = (2a/D)\sin\beta$$

Substituting (A-2) into the above gives

$$\sin\alpha = \{[1 - (d/D)^2\sin^2\beta]^{\frac{1}{2}} - (d/D)\cos\beta\}\sin\beta \qquad \text{(A-5)}$$

Equations A-2, A-4, and A-5 completely define the geometric parameters of the ray path in terms of the refraction angle.

Substituting (A-3) into (A-2), (A-4), and (A-5) allows the ray path to be defined in terms of the angle of incidence of the ray γ.

The results are summarized below:

$$2a = [D^2 - d^2 (V_s/V_w)^2 \sin^2\gamma]^{1/2} - d [1 - (V_s/V_w)^2 \sin^2\gamma]^{1/2} \qquad \text{(A-6)}$$

$$\sin\theta = (d/D) (V_s/V_w) \sin\gamma \qquad \text{(A-7)}$$

$$\sin\alpha = \{[1 - (d/D)^2 (V_s/V_w)^2 \sin^2\gamma]^{1/2} - (d/D)[1 - (V_s/V_w)^2 \sin^2\gamma]^{1/2}\} \times [(V_s/V_w) \sin\gamma] \qquad \text{(A-8)}$$

The offset E in Figure A-1 is

$$E = d/2 \sin\gamma \qquad \text{(A-9)}$$

$$E = d/2 (V_w/V_s) \sin\beta \qquad \text{(A-10)}$$

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In the attachment of copper rotating band to a projectile body, craters, unbonds, and crack systems may develop. These defects may produce serious structural failures or aerodynamic instability. The ultrasonic C-scan evaluation of rotating bands on 8-inch-diameter projectiles was conducted using both longitudinal and shear angle techniques to assess the integrity of the weld overlay band and the shell body. The longitudinal wave method was used to inspect for unbond areas at the interface of the shell body and rotating band. From this work it was ascertained that ultrasonic C-scanning yields and accurate representation of unbond areas developed during the weld overlay method of attaching rotating bands. Cracks and craters at the outer diameter of the steel body were investigated by means of the shear angle beam method. It was found that at an optimum shear angle of 45°, longitudinal saw cuts of various depths and also actual weld craters in the steel shell are readily detected and recorded with C-scan techniques.

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PERLIMINARY DEVELOPMENT DF ULTRASONIC C-SCAN
TEST METHODS AND STANDARDS TO DETERMINE
PROJECTILE-ROTATING BAND INTEGRITY -
Robert H. Brockelman, Robert A. Muldoon
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Key Words

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